Radio galaxies and their central machines

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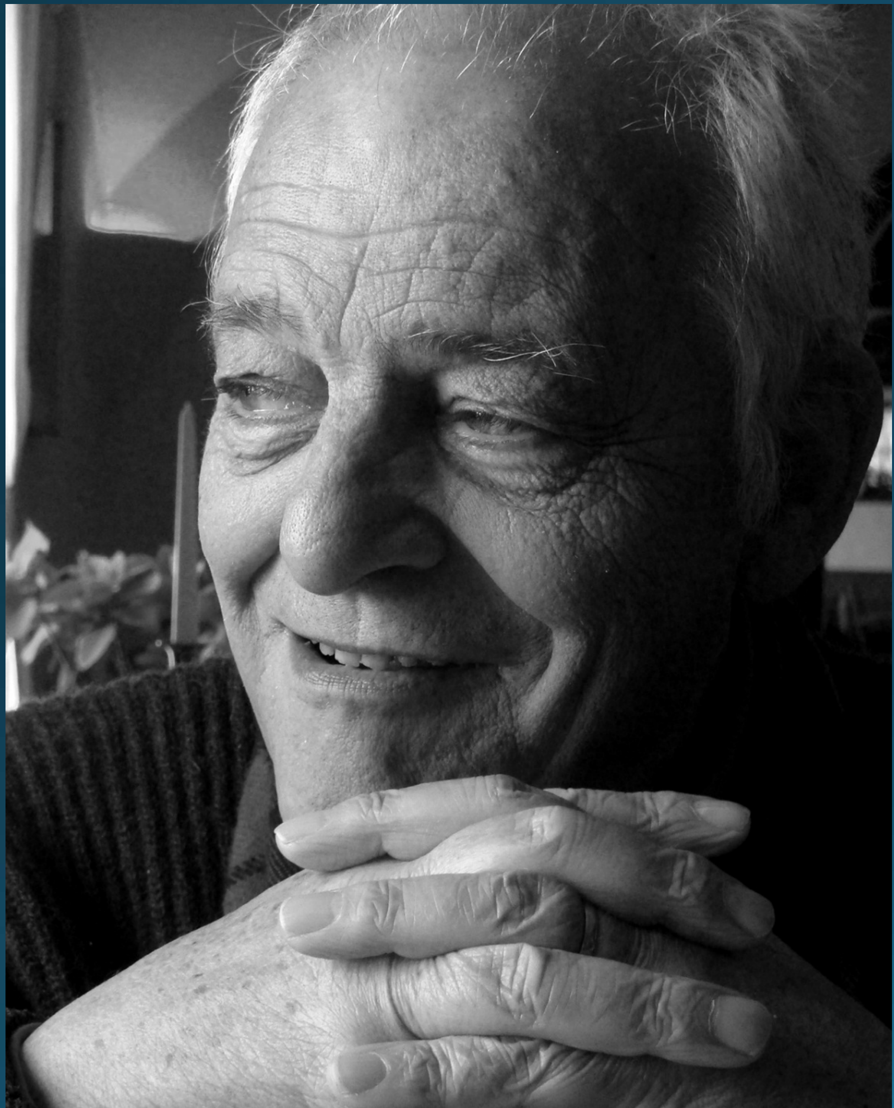
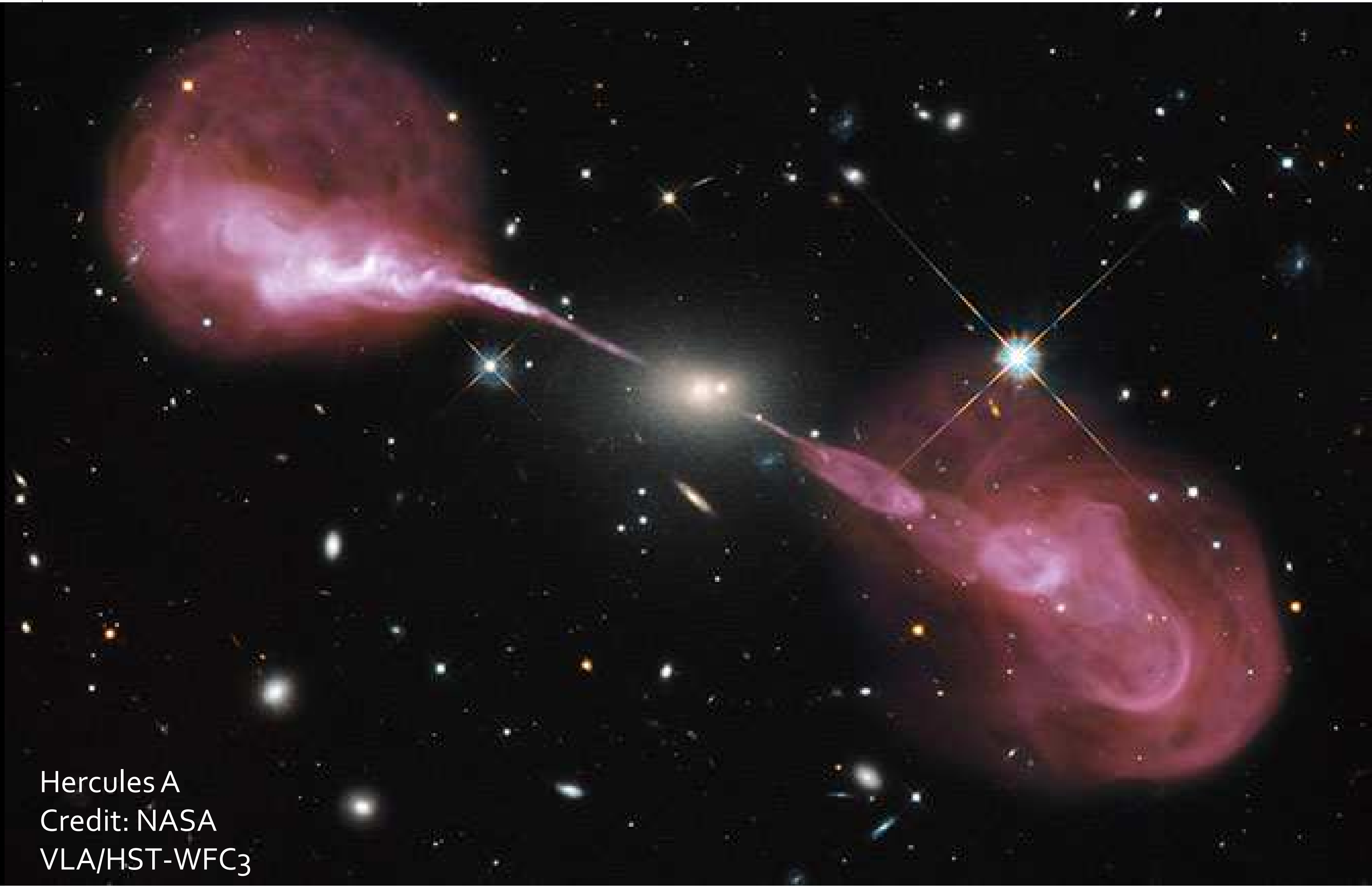


In memorian

✝ Eckart Lorenz
June 21st, 2014

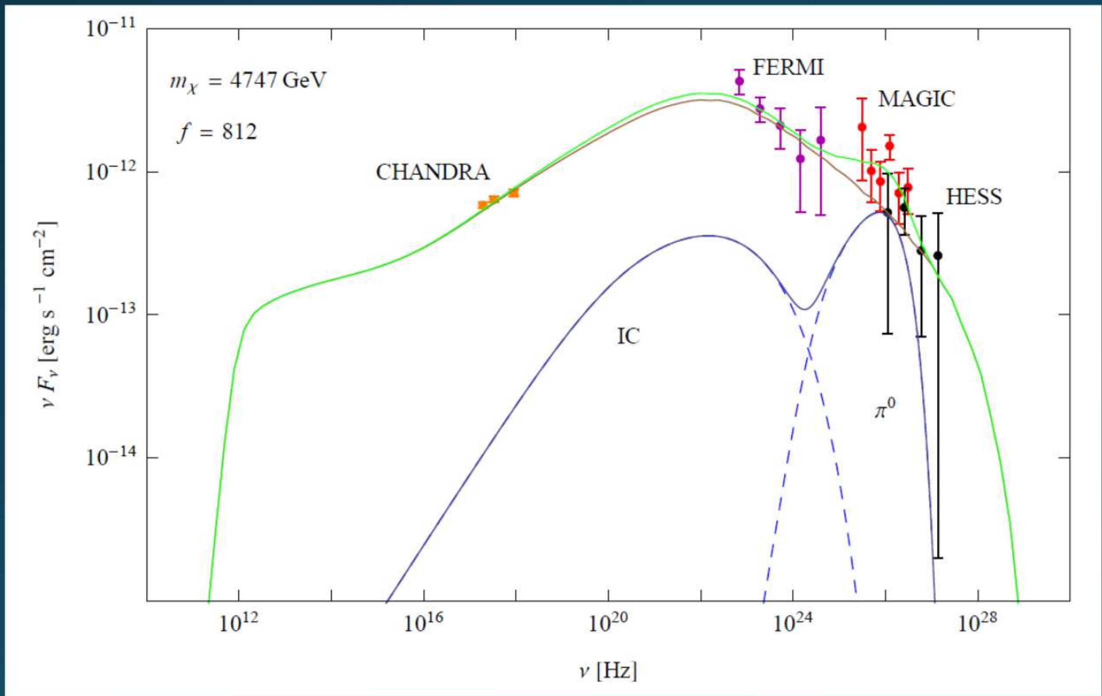

Hercules A
Credit: NASA
VLA/HST-WFC3

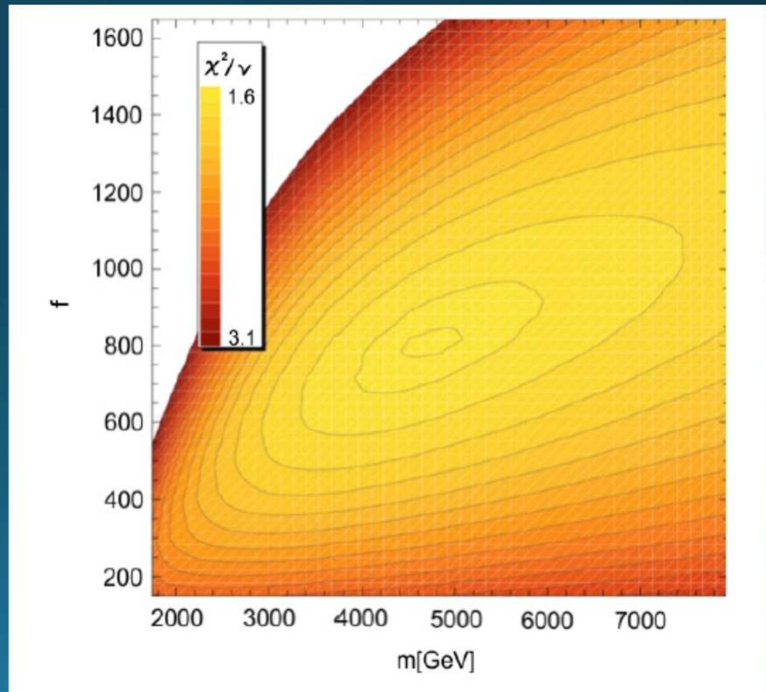
Why care about radio galaxies ?

- Possible sites of origin for
  - Dark Matter annihilation radiation
  - UHE Cosmic Rays
  - PeV Neutrinos

Radio galaxies provide natural background for dark matter searches

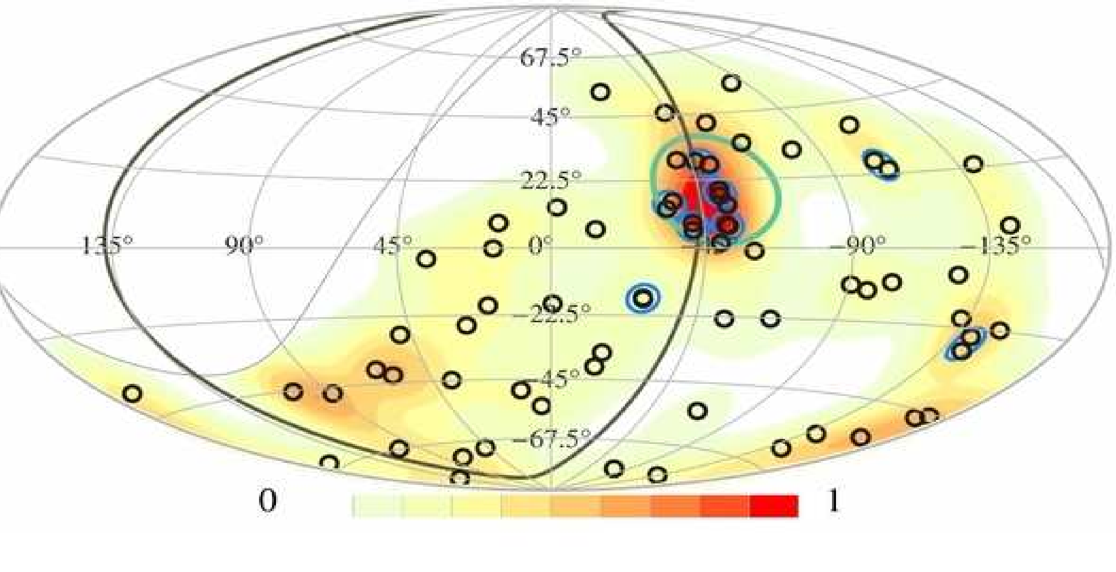
Saxena, Summa, Elsässer, Rüger, & Mannheim, EPJC 71, 1815 (2011)

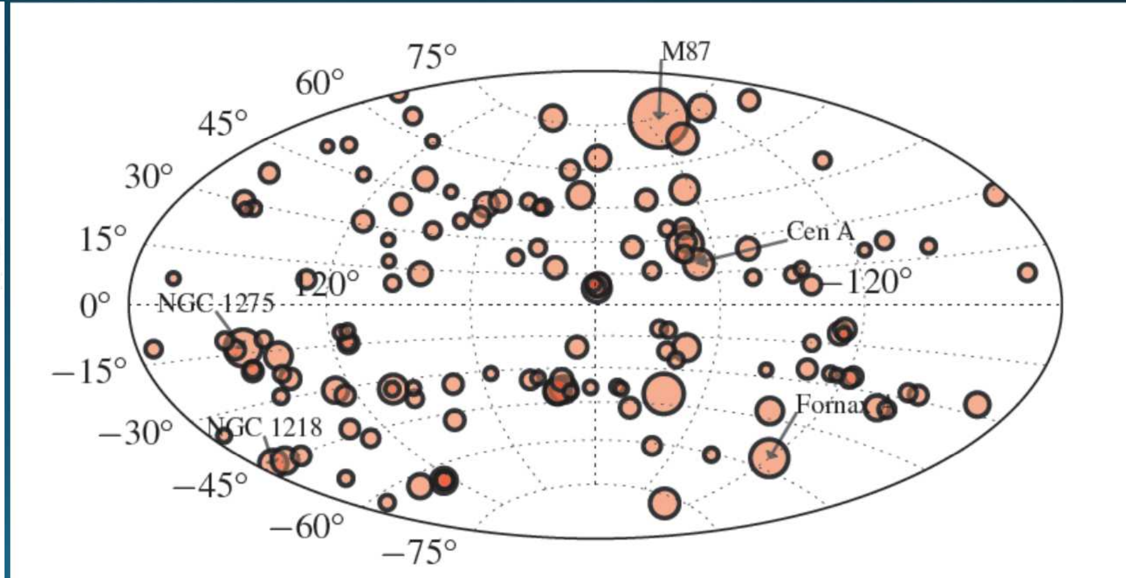




Radio galaxies are plausible sources of UHE CRs

Rieger & Aharonian, A&A 506, L41 (2009) based on Rieger & Mannheim, A&A 353, 473 (2000)



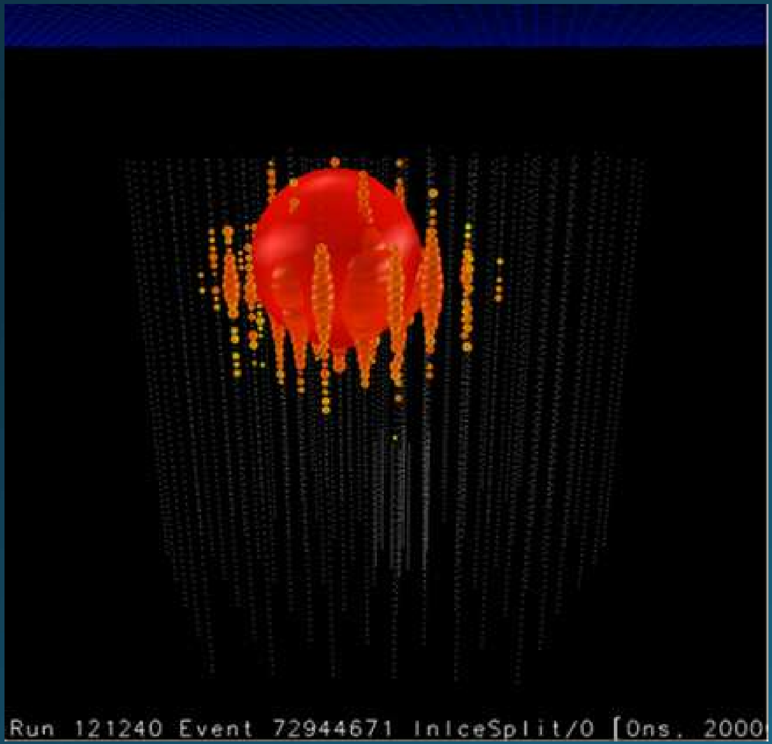


PIERRE AUGER UHE CR events above 5 x 10^{19} eV (from Yüksel, et al., ApJ. 2012)

Radio galaxies in 125 Mpc (from Velzen et al., A&A, 2012)
Correlation with regions of high galaxy density

Radio galaxies are plausible sources of PeV neutrinos

Icecube detects sotropic intensity of 1.2 x 10^{-8} GeV cm^{-2} s^{-1} st^{-1} consistent with „model A" (KM, Aph, 1995)
„Big Bird" event with 2PeV detected by IceCube consistent with direction of Cen A



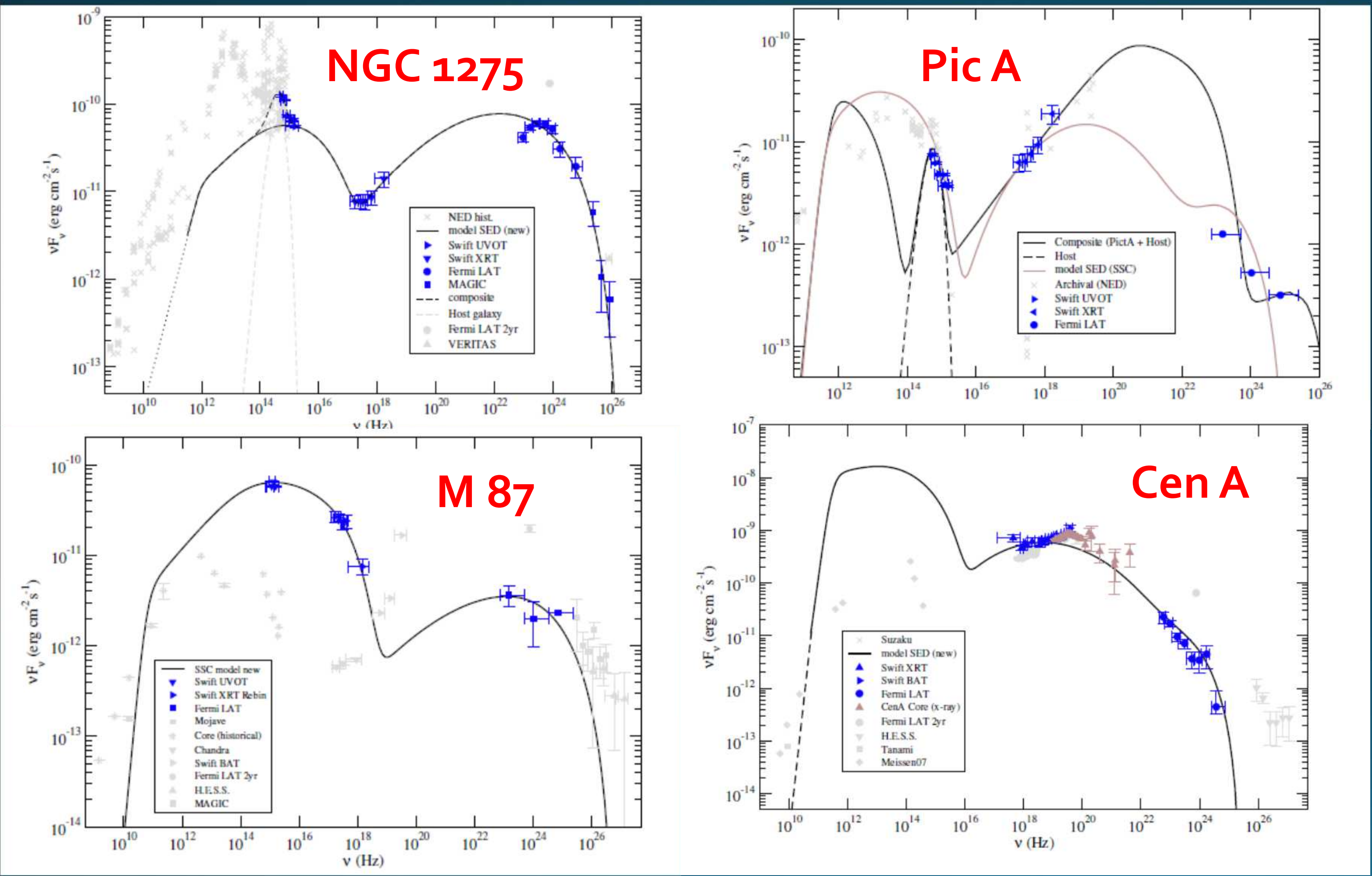
Big Bird (event #35) DEC -55.8 RA 208.4
Cen A DEC -43.02 RA 201.37
(directional uncertainty for cascades is ~ 10°)

Ernie & Bert events consistent with blazar origin (Krauß, KM, et al., A&A, 2014, in press)

Source	F_γ(erg cm^{-2} s^{-1})	events
0235−618	$(1.0^{+0.5}_{-0.5}) \times 10^{-10}$	$0.19^{+0.04}_{-0.04}$
0302−623	$(3.4^{+0.7}_{-0.7}) \times 10^{-11}$	$0.06^{+0.01}_{-0.01}$
0308−611	$(7.5^{+2.9}_{-2.9}) \times 10^{-11}$	$0.14^{+0.05}_{-0.05}$
1653−329	$(4.5^{+0.5}_{-0.5}) \times 10^{-10}$	$0.86^{+0.10}_{-0.10}$
1714−336	$(2.4^{+0.5}_{-0.6}) \times 10^{-10}$	$0.46^{+0.10}_{-0.12}$
1759−396	$(1.2^{+0.3}_{-0.2}) \times 10^{-10}$	$0.23^{+0.50}_{-0.40}$
Total		1.9 ± 0.4

Do we understand the origin of the TeV emission from radio galaxies ?

- hadronic / leptonic
- location of emission zone
- nature of variability

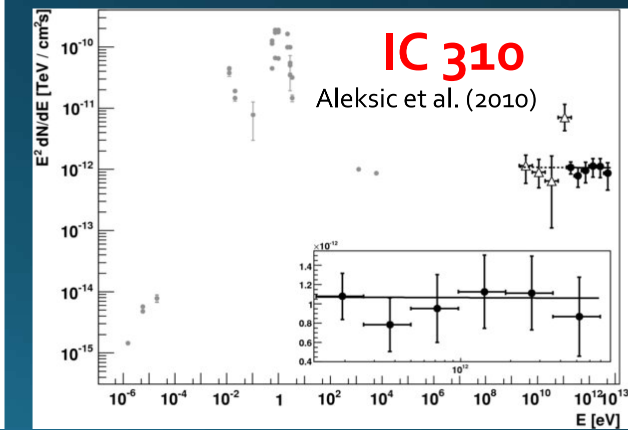


Fermi-LAT radio galaxies with simultaneous SEDs

M87, Cen A, and NGC 1275 also at TeV energies

SSC and hybrid (SSC+hadronic) model fits

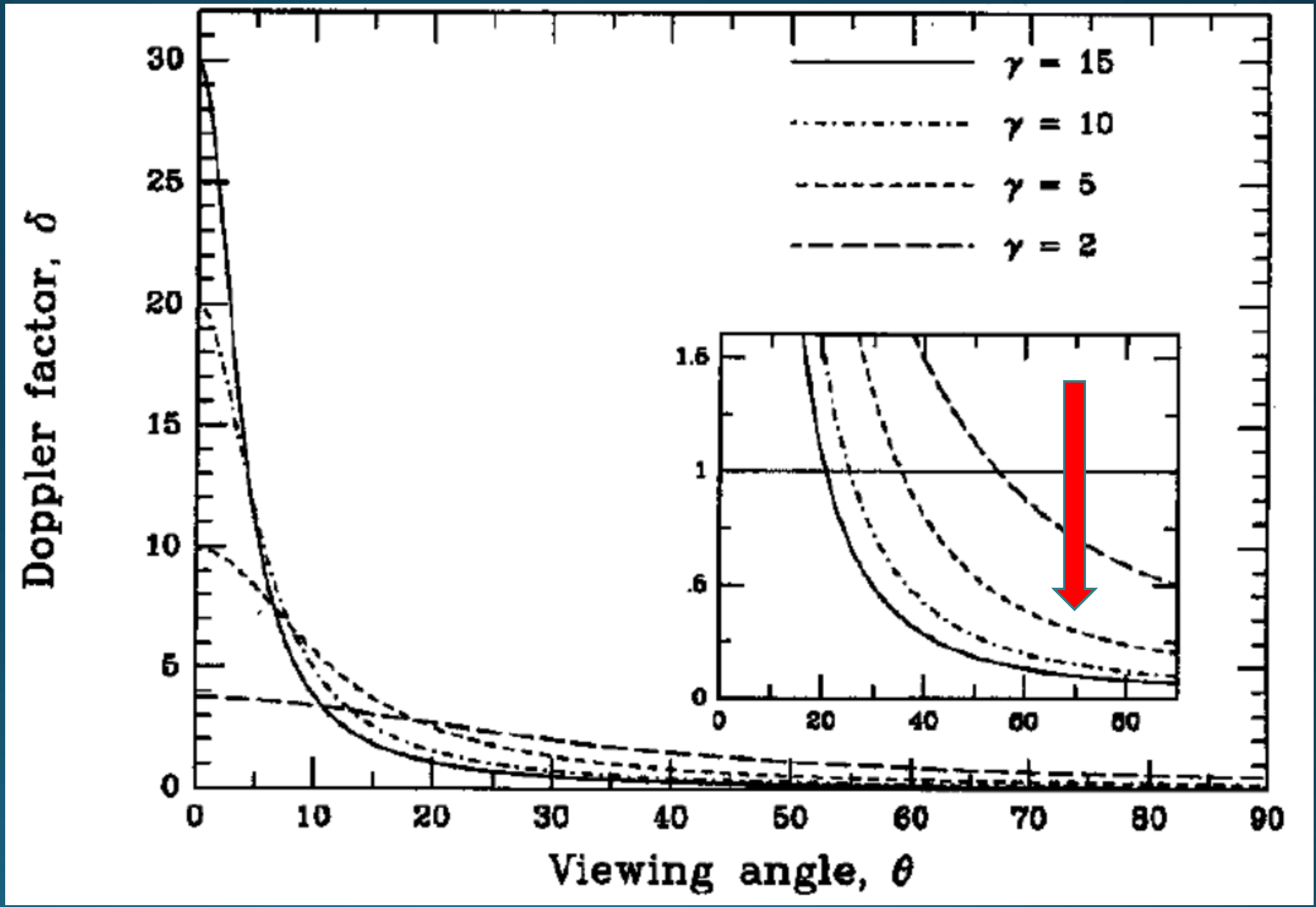
(Spanier & Weidinger, 2012, IJMPS 8, 293)



Saxena, KM, et al. „Analysis and Spectral Energy Distributions of Gamma-Detected Radio Galaxies “, in preparation (2014)

Emission from misaligned blazar jets should be very faint due to Doppler-deboosting $D \sim 1 / \Gamma$

Emission from stationary components (core, hot spots, lobes) should dominate total flux

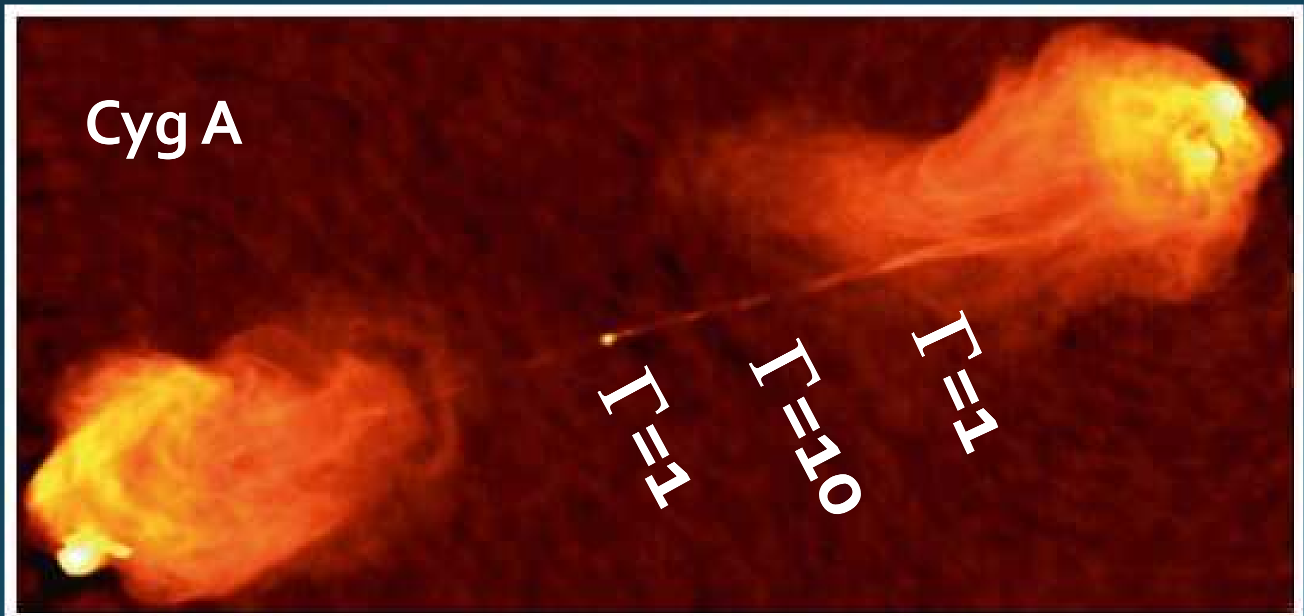


Simultaneous SED fits with the self-consistent two-zone SSS model of Spanier & Weidinger (2012) do not show this. In the case of IC310, we do not obtain an acceptable fit at all.

Radio Galaxy	Model	K [cm^{-3}]	Γ_0	B [G]	R_{rad} [cm]	R_{acc} [cm]	t_{acc} / t_{esc}	a	δ	K_p [cm^{-3}]	Γ_{0p}
NGC 1275	SSC	$1.9 \cdot 10^6$	15	0.28	$2.5 \cdot 10^{15}$	$3.5 \cdot 10^{14}$	1.40	150	32.5	-	-
Pictor A	SSC	$2.5 \cdot 10^5$	65	0.47	$2.95 \cdot 10^{16}$	$1.77 \cdot 10^{15}$	1.11	100	21	-	-
Pictor A	Hybrid	$8.6 \cdot 10^9$	30	18	$7.25 \cdot 10^{16}$	$3.65 \cdot 10^{13}$	1.19	50	11	$1.9 \cdot 10^{11}$	10
M 87	SSC	$1.9 \cdot 10^6$	10	0.24	$6.0 \cdot 10^{15}$	$1.0 \cdot 10^{14}$	1.43	20	14.5	-	-
Centaurus A	SSC	$5.5 \cdot 10^4$	50	0.52	$5.0 \cdot 10^{15}$	$5.3 \cdot 10^{14}$	1.75	$5 \cdot 10^3$	21	-	-

Possible solution: Spine-Sheath models with relativistic spine and slower sheath (e.g., Taveccho & Ghisellini, 2008, 2014 for M87 and NGC1275)

Another obvious approach: Consider stationary base of the jet where it is launched from the hot thermal accretion flow

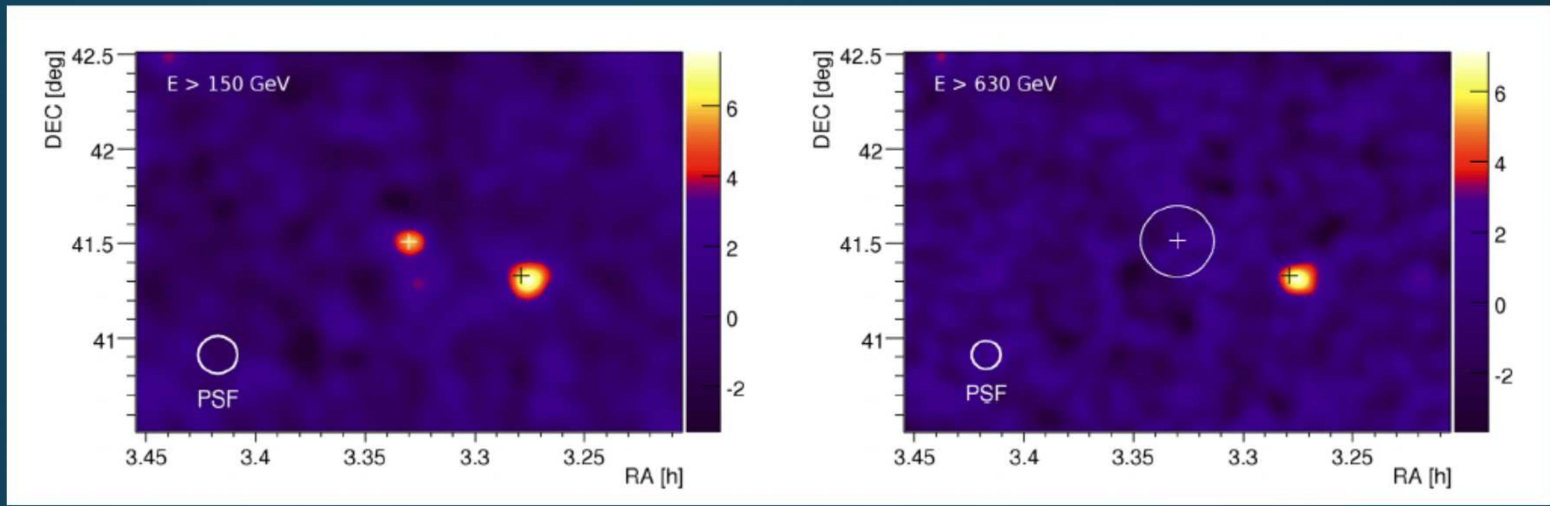


Credit: NRAO (VLA@5GHz)
Carilli & Barthel 1996

Mass loading by thermal pair production (BZ model) works well for FRII and FR I/NLSy1 radio galaxies ($\tau_{\gamma\gamma}$>1)

In FRI galaxies and BL Lacs with low accretion rate, the thermal pair density may fall below n_{GJ} (Levinson & Rieger, 2011)

IC 310



MAGIC

ApJ 723, L207 (2010)

A&A 541, A99 (2012)

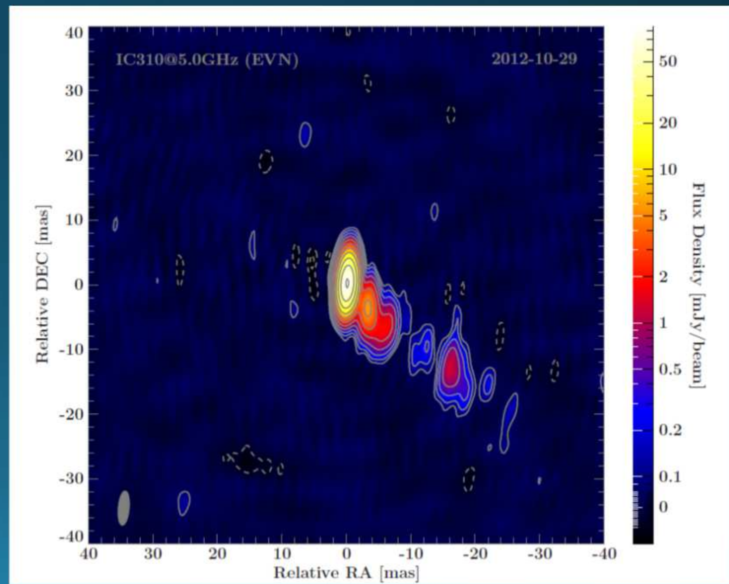
A&A 563, 91 (2014)

submitted (2014)

Radio / multi-wavelength

Kadler et al. A&A 538, L1 (2012)

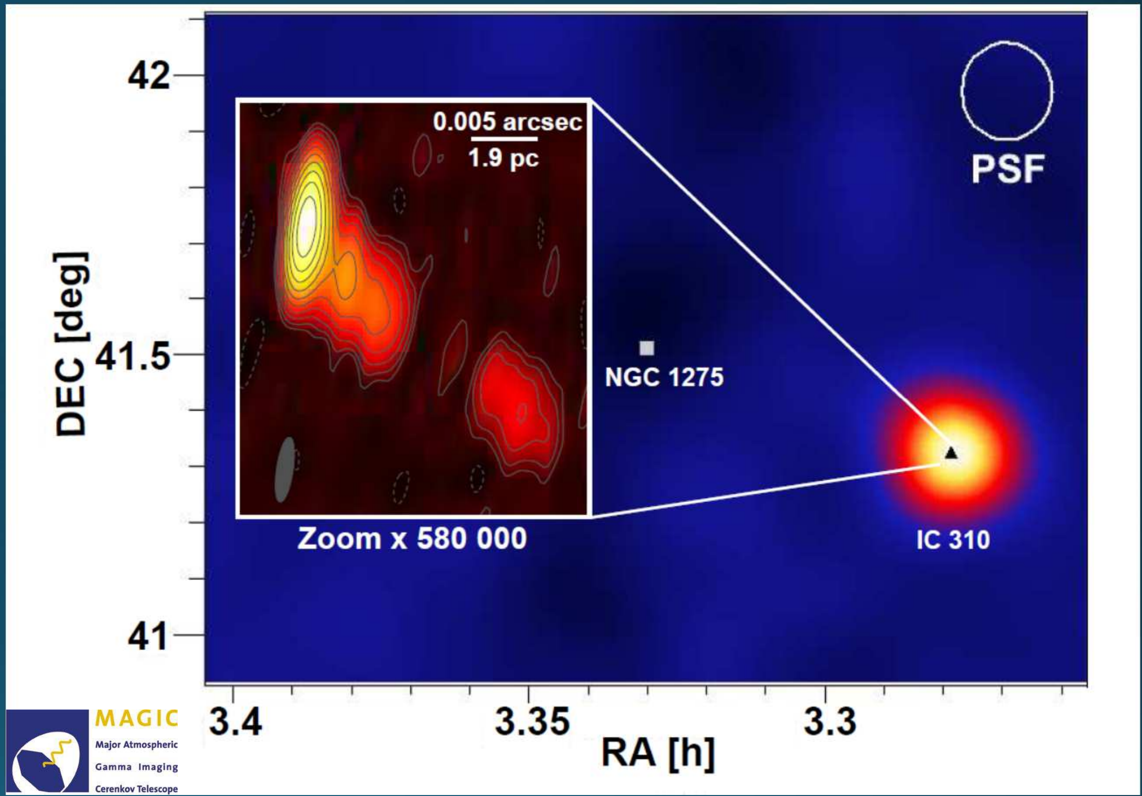
Schulz et al., EVN Newsletter 37 (2014)



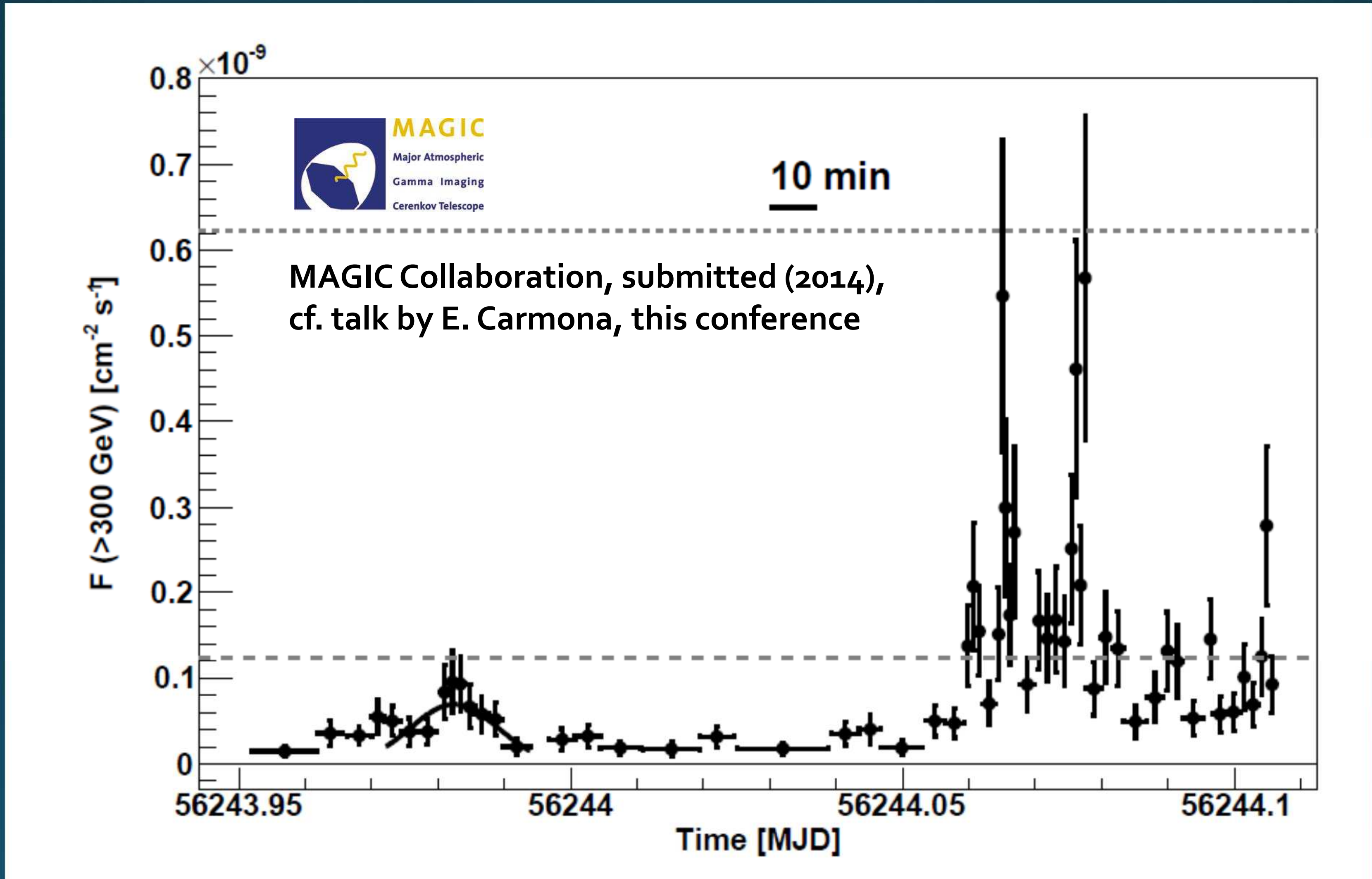
IC 310

- No plausible SSC fit
- VLBI shows blazar-type jet (Kadler, Eisenacher, KM, et al., A&A, 2012)
- Orientation angle 10°-20°
- Unusually hard TeV spectrum $\Gamma = 1.8$
- Large-amplitude TeV variability

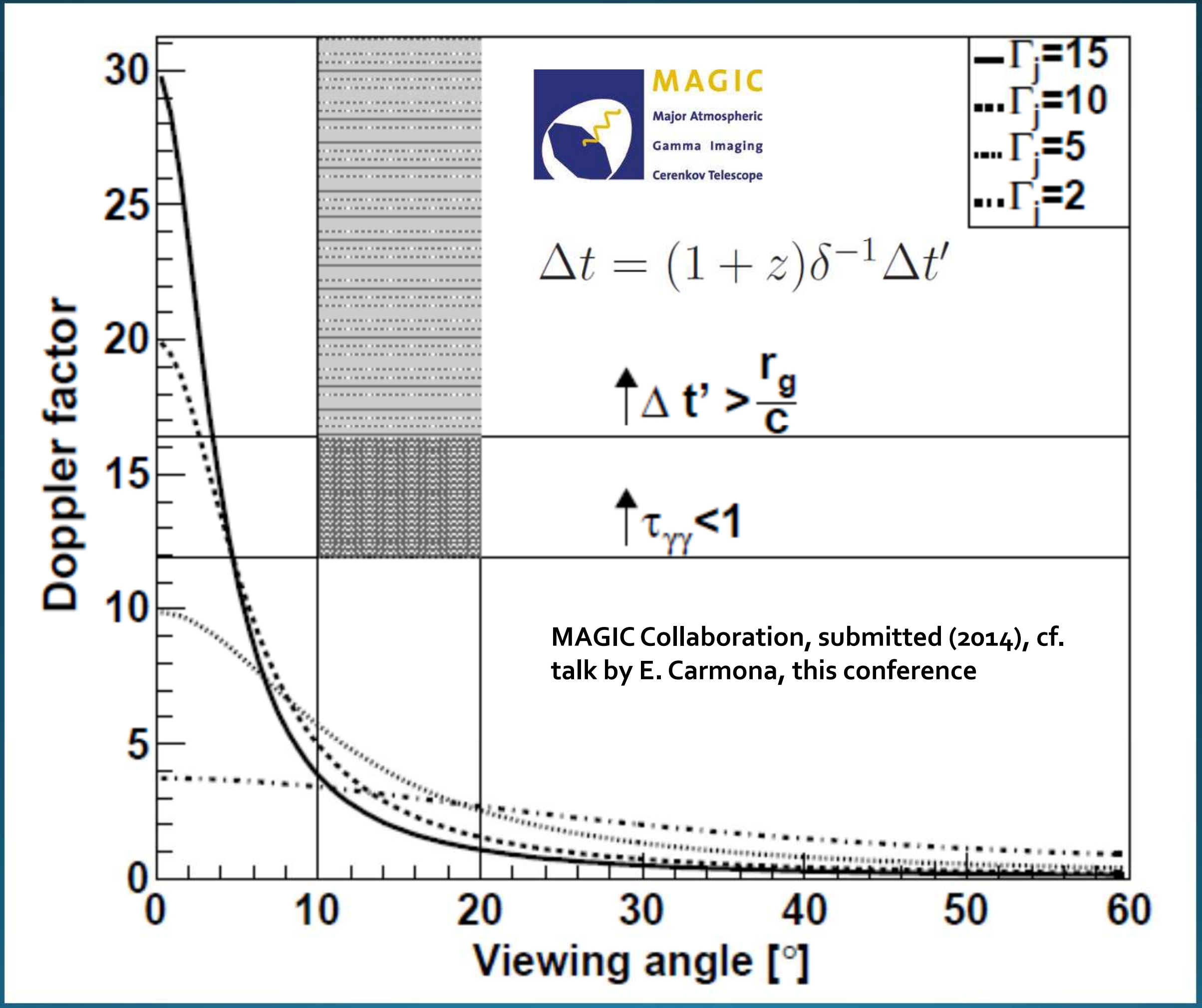
Δt = 1 min = 0.05 r_g/c

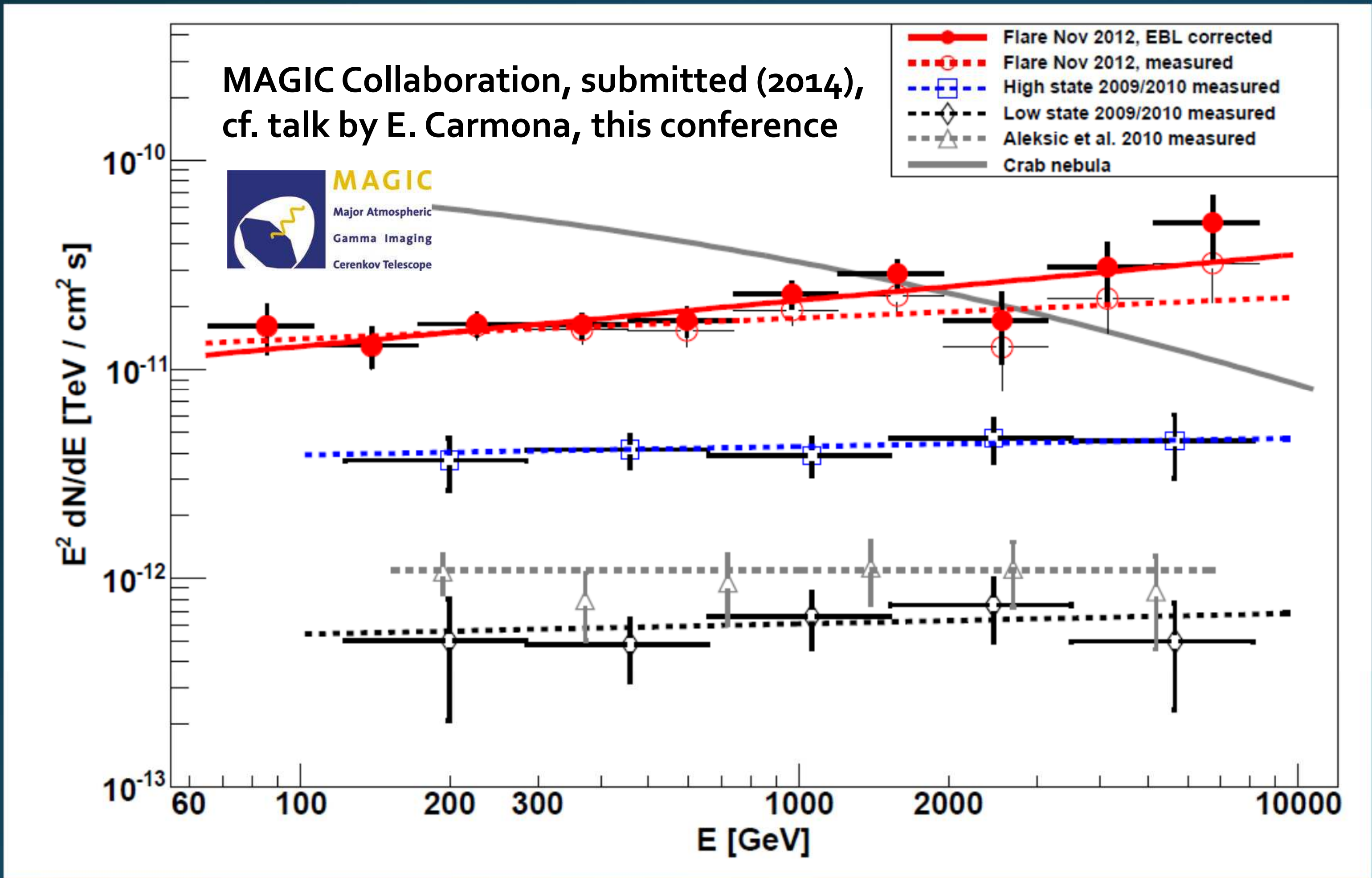


In-depth study lead by D. Eisenacher and J. Sitarek for the MAGIC Collaboration jointly with multi-wavelength astronomers Kadler, Schulz, Ros, Bach, Krauß, Wilms, submitted (2014)


MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope
10 min
MAGIC Collaboration, submitted (2014),
cf. talk by E. Carmona, this conference
F (>300 GeV) [cm^{-2} s^{-1}]
×10^{-9}
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
56243.95
56244
56244.05
56244.1
Time [MJD]

No bulk Lorentz factor meets all constraints !





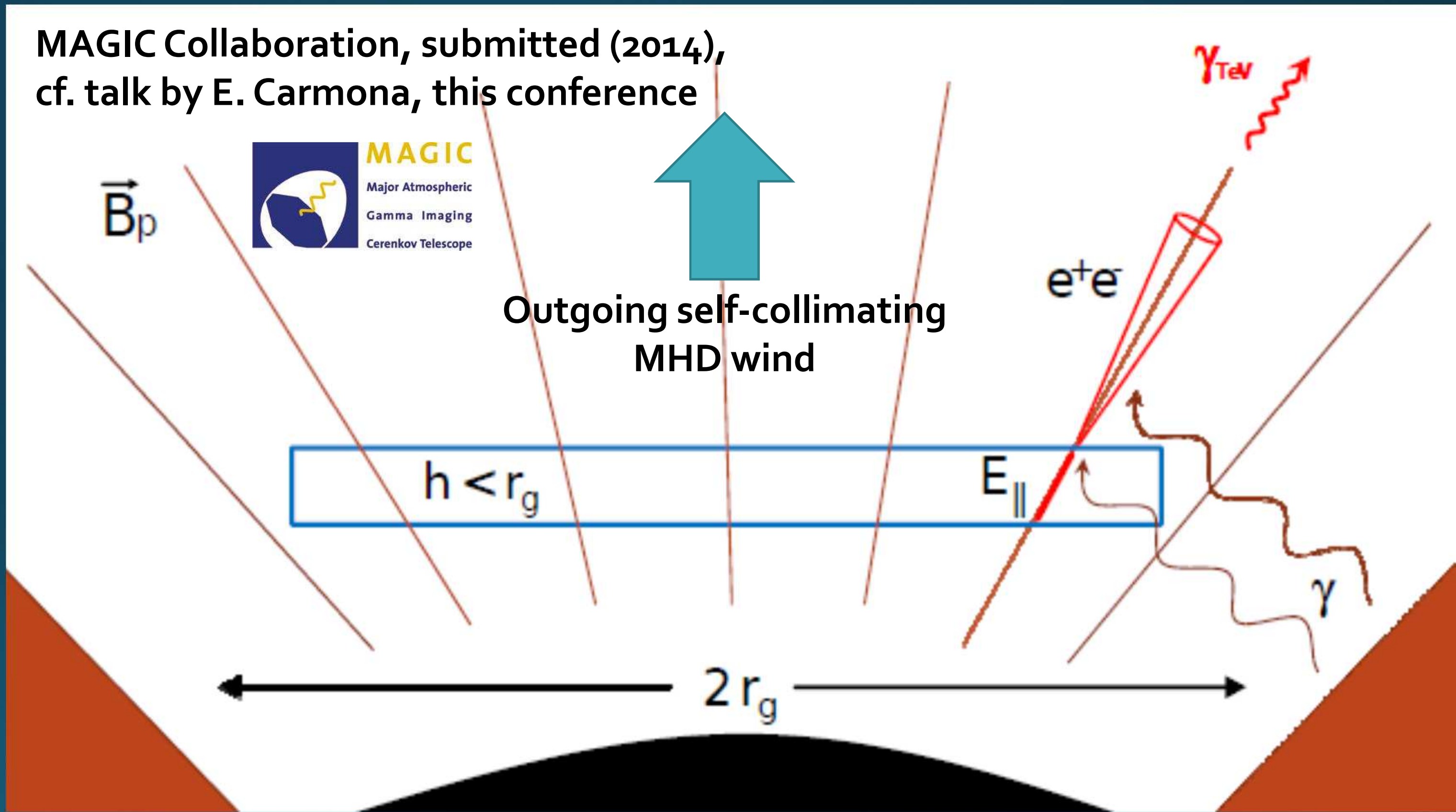
Spectral slope Γ=1.8 consistent with unsaturated cascades
(Mannheim, PRD, 1993)

Cascades stop before reaching $m_e c^2$ due to low IR photon density of hot torus

Emission from vacuum gap due to insufficient ($<n_{GJ}$) loading of magnetosphere with thermally produced pairs

Beskin et al. 1992
Punsly, 1998
Neronov et al. 2009
Levinson & Rieger, 2011

Variability due to fluctuations of seed particles

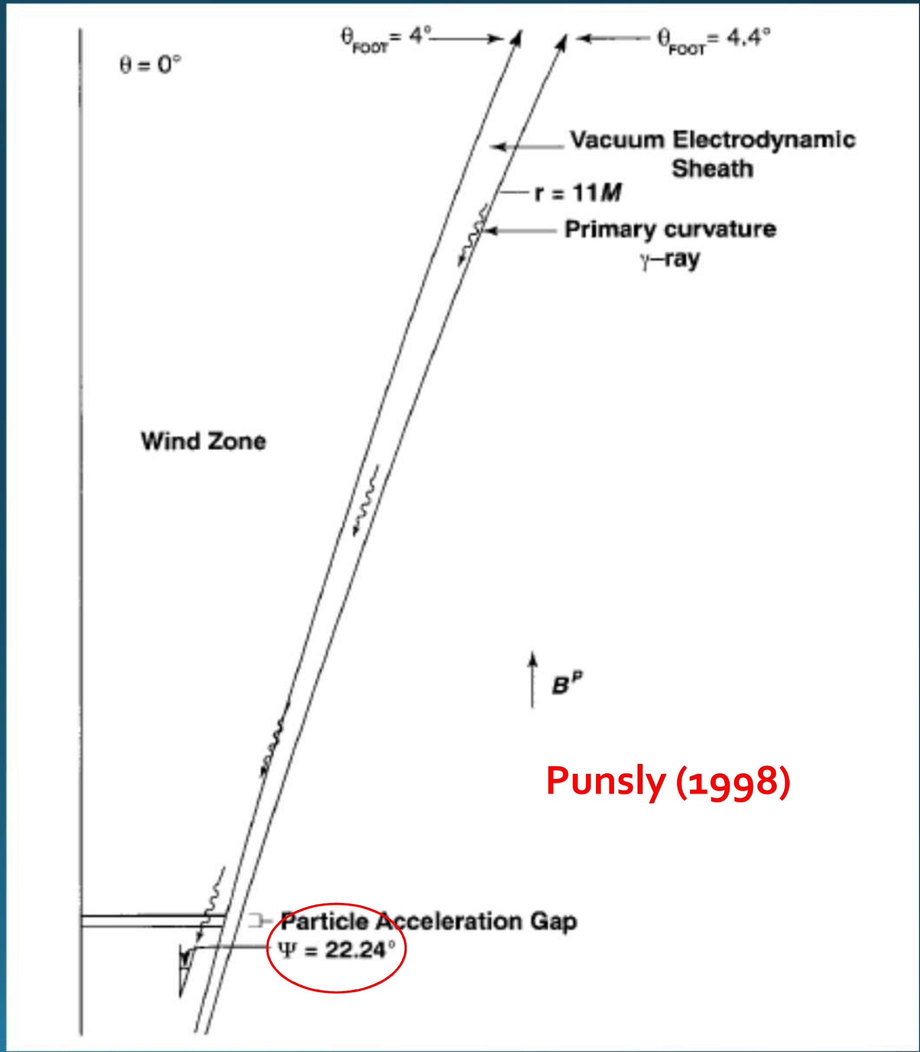


$h \sim 0.1\, r_g$; $e\Delta V = 10^{17}$ eV ; $L_{acc} = 10^{38}$ erg/s ; $T = 2 \times 10^9$ K

Lightnings from central machine?

Pulsar analogy

- Within light cylinder: particle acceleration by gaps or currents sheets
- In MHD wind zone: particle acceleration at shocks



Punsly (1998)

Summary

- ✓ Radio galaxies are prime targets for TeV astrophysics.
- ✓ High-energy emission from central regions of clusters of galaxies where also dark matter concentration is highest.
- ✓ Good candidates for UHE CR and PeV neutrino emission
- ✓ SEDs different from blazar SEDs at a larger angle.
- ✓ Variability points to emission from central engine.
- ✓ Pulsar analogy.

Thanks to my collaborators, most of all to:

- Dorit Eisenacher and Julian Sitarek (for the MAGIC Collaboration)
- Matthias Kadler, Robert Schulz und Felicitas Krauß (IC310 radio images, Ernie &Bert blazars)
- Dominik Elsässer and Sheetal Saxena (DM contraints from M87 SED)